Accounting for the Effect of Runoff Reduction on Runoff Hydrographs
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Center for Watershed Protection, 04/21/08

1. Background and Introduction

Historically, stormwater management has focused on peak runoff rate control, which requires a site designer to generate a post-development runoff hydrograph and a pre-development runoff hydrograph and manage the difference between the two.

More recently, site designers have been introduced to water quality control criteria that are intended to manage the "capture and treat" (e.g. water quality) volume,

Most recently, communities have developed stormwater runoff reduction criteria that specify a runoff volume that must be "captured and reduced" (reused, evaporated, infiltrated or otherwise retained on site). A particular challenge is providing credit for these runoff reduction volumes within rainfall/runoff models.
In principle, when runoff reduction practices are used to capture and retain or infiltrate runoff, downstream stormwater management practices shouldn't have to detain, retain or otherwise treat the volume that is removed. In other words, runoff reduction should be accounted for in stormwater runoff computations

While it is not easy to predict the absolute hydrograph modification provided by reducing stormwater runoff volumes, it is clear that reducing runoff volumes will have an impact on the runoff hydrograph of a development site. The challenge facing stormwater managers and site designers is developing a hydrograph generating technique that provides adequate credit for stormwater runoff volumes that are reduced on site.

2. Objectives for Integration

In order to be useful to stormwater managers and site designers, the method developed and used must meet a number of objectives:

1. Field performance – solves real problems (water quality, channels, long term maintenance/performance)
2. More efficiency – doesn't lead to the overbuilding of BMPs (size, #)
3. Incentivizes RR/BSD – leads to meaningful results if the designer applies ample effort to use RR practices
4. Simple – easy to understand & use, fits into spreadsheets + TR55, other common models
5. Allows range of practices – broadens the suite of BMPs to use at a site – basins are not "automatic."
6. Accountability for the local PW guys – today's plan approvals do not equal tomorrow's drainage complaints
7. Defensible – makes sense with the site hydrology; engineers believe it is realistic and plausible

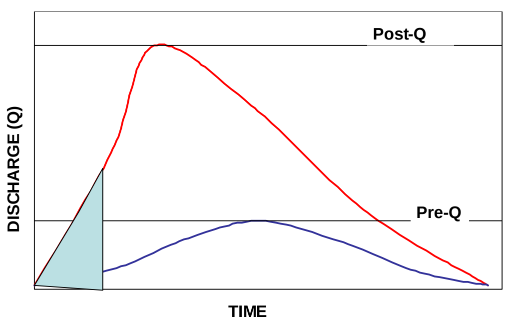
8. Accurate – reflects actual site hydrology
9. Adaptable to Different Pollutants -- Addresses pollutants of concern for different applications
10. Relevant at Subwatershed – Can be tied to stormwater benchmarks for subwatershed, such as flow, volume, load reduction

3. Different Approaches and Methods

There are a variety of approaches that can be used to adjust the runoff hydrograph to account for the effect of runoff reduction practices in a site drainage area. This section describes five approaches, all of which use the NRCS unit hydrograph method as a baseline. For some methods, a hydrograph for the site without runoff reduction practices is generated, which is then adjusted. Other methods initially adjust the runoff depth that results from a site with runoff reduction practices, and then generates a hydrograph. Different approaches are discussed below.

Truncated Hydrograph (Volume Diversion)

The truncated hydrograph approach applies runoff reduction in-line at the outlet of a drainage area. For this particular option, a runoff hydrograph for the original site prior to implementing runoff reduction practices is generated. The volume of runoff reduced by runoff reduction practices is then subtracted from the front portion of the hydrograph. If the amount of runoff reduced is less than the volume up to the hydrograph peak, then no reduction in the peak flow or time to peak is reflected. As a result, this approach often results in conservative design estimates of the resulting peak flow.



Hydrograph Scalar Multiplication

Similar to the previous approach, the hydrograph scalar approach begins by generating a hydrograph for the original site prior to implementing runoff reduction practices. In this particular approach, the hydrograph is then multiplied by a scalar, which adjusts the magnitude of the original site hydrograph. The scalar is simply the ratio of runoff generated from the site with runoff reduction practices to the runoff generated from the original site (with no runoff reduction practices). The effect of runoff reduction practices is applied over the entire hydrograph rather than at the beginning. As a result, the degree to which the peak flow rate would be reduced is decreased, resulting in a conservative peak flow rate estimate.

Precipitation adjustment- Subtract retention from rainfall

This approach adjusts the NRCS runoff depth formula prior to generating a hydrograph, eliminating the need to develop an original site hydrograph. For this approach, the amount of runoff reduced is subtracted from the rainfall depth (Eqn. 1), and hydrograph calculations are subsequently performed.

$$Q = \frac{\left((P-R)-I_a\right)^2}{\left((P-R)-I_a\right)+S} \qquad (1)$$

where P=rainfall depth (in), R = Reduced Runoff (in), Q= Runoff (in), I_a *= initial abstraction, S = potential maximum retention after runoff begins*

The problem with this approach is that the volume of runoff reduced is never fully accounted for, as the change in runoff volume generated will always be less than the amount of runoff reduced. Further, adjusting the rainfall is not truly representative of what actually occurs over the site.

Adjusted CN

The Adjusted CN approach adjusts the NRCS runoff depth formula by changing the curve number (CN) for the portion of the site draining to runoff reduction practices. Site runoff is calculated using Equations 2-4. The CN can be adjusted to an improved site condition; for example, to a meadow in good condition.

$$S = \frac{1000}{CN} - 10 \qquad (2)$$

$$I_a = 0.2S \qquad (3)$$

$$Q = \frac{\left((P-I_a\right)^2}{\left((P-I_a\right)+S} \qquad (4)$$

This approach reduces the runoff generated from the site and the runoff peak flow rate; however, no delay in the time to peak is reflected. Further, the effect of runoff reduction is distributed over the entire course of the storm, as opposed to occurring at the beginning. As a result, the degree to which the peak flow rate would be reduced is decreased, resulting in a conservative peak flow rate estimate.

Runoff adjustment - Subtract retention from runoff

The runoff adjustment approach also adjusts the NRCS runoff depth formula prior to generating a hydrograph. The amount of runoff reduced is subtracted from the calculated site runoff (Eqn. 5). A hydrograph is then generated incrementally through the unit-hydrograph method that reflects the initial reduction of runoff volume and the subsequent time to peak delay and peak flow reduction.

$$Q = \frac{\left((P - I_a\right)^2}{\left((P - I_a\right) + S} - R \qquad (5)$$

This approach seems to accurately describe what may occur over a site drainage area, but it is problematic in that TR-55 and TR-20 cannot be used to generate the resulting hydrograph. While the methodology is straightforward, the hydrograph convolutions are time-consuming and involved.

4. Preferred Method(s)

(A) Best Long-Term: Runoff adjustment - Subtract retention from runoff

Of the methods listed above, *Runoff adjustment – Subtract retention from runoff,* is the preferred method. The philosophy behind this method is the similar to the philosophy behind the *Truncated Hydrograph* method – site runoff reduction practices, will accept and retain a portion of the initial runoff during a given rain event, which will modify the ultimate volume of runoff from the site, as well as the shape of the ultimate runoff hydrograph.

The key difference between the two methods is how the initial runoff is "subtracted." As discussed above, for the *Truncated Hydrograph* method, a total site runoff hydrograph is created, and then the volume provided by the runoff reduction practices is subtracted from the hydrograph's rising limb. For the *Runoff adjustment – Subtract retention from runoff* method, the subtraction is performed at an earlier stage, before the site hydrograph is generated. In order to generate a site hydrograph for an entire storm event, the storm is divided into discreet time periods. For each time period, an excess runoff rate is determined based upon watershed characteristics and the amount of rainfall during that time period. This excess runoff rate is then translated into a hydrograph. The site hydrograph for the entire storm event is created by summing each of these hydrographs over the duration of the storm. Instead of making a subtraction from the site hydrograph, the *Runoff adjustment – Subtract retention from runoff* method subtracts each individual time period hydrograph, until the volume of runoff reduction has been reached.

This is the preferred method, because it not only subtracts the runoff reduction volume at the beginning of the hydrograph, but also tends to reduce the peak flow and extend the time to peak of the site hydrograph, all of which are expected effects of utilizing runoff reduction practices. The effects on peak flow and time to peak are due to the fact that a time period hydrograph extends longer than the period of rainfall it corresponds to. Therefore, subtraction of an initial number of time period hydrographs has a significant effect on the rising limb of the site hydrograph, but the effect is also extended through the peak, changing both the peak, and the time to peak.

While this preferred method appears to model the actual hydrology of runoff reduction practices most closely, it is a difficult and time-consuming method. Subtraction of time period hydrographs requires that the time period hydrographs be individually calculated throughout a storm event. This time-consuming activity is rarely performed, as there are many hydrology computer programs that have been designed to do this and calculate a total site hydrograph. However, existing hydrology programs do not have the capability to subtract individual hydrographs from the site hydrograph and account for runoff reduction practices in this manner.

(B) Good Choice for Short-Term: Adjusted CN

Given the software and assimilation challenges of the *Runoff adjustment* method, the second best option is *Adjusted CN.* This method is a plausible way to reduce volumes and peak rates, and fits into the models that are understood by design consultants and plan reviewers.

5. Next Steps

- Vet the various methods with DCR's workgroup.
- Continue to flesh out the preferred methods, using examples and sample hydrographs to see the effect, and the actual benefit of applying RR practices.
- Perhaps work to develop some software applications (would require funding)
- Fold a preferred method into the Runoff Reduction compliance spreadsheet
- Use the integrated approach at future charettes